Mediators of Physical Activity Adherence: Results from an Action Control Intervention in Couples

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Abstract: BACKGROUND: Behavior change interventions targeting self-regulation skills have generally shown promising effects. However, the psychological working mechanisms remain poorly understood. PURPOSE: We examined theory-based mediators of a randomized controlled trial in couples targeting action control (i.e., continuously monitoring and evaluating an ongoing behavior). Self-reported action control was tested as the main mediating mechanism of physical activity adherence, and in addition self-efficacy and received social support from the partner. METHODS: Overweight individuals (N = 121) and their heterosexual partners were randomly allocated to an intervention (information + action control text messages) or a control group (information only). Across a period of 28 days, participants reported on action control, self-efficacy, and received support in end-of-day diaries, and wore triaxial accelerometers to assess stable between-person differences in mediators and the outcome adherence to recommended daily activity levels (30 min of moderate activity in bouts of at least 10 min). RESULTS: On average, participants in the intervention group showed higher physical activity adherence levels and higher action control, self-efficacy, and received support compared to participants in the control group. Action control and received support emerged as mediating mechanisms, explaining 19.7 and 24.6% of the total intervention effect, respectively, in separate analyses, and 13.9 and 22.2% when analyzed simultaneously. No evidence emerged for self-efficacy as mediator. CONCLUSIONS: Action control and received support partly explain the effects of an action control intervention on physical activity adherence levels. Continued research is needed to better understand what drives intervention effects to guide innovative and effective health promotion. TRIAL REGISTRATION NUMBER: (controlled-trials.com ISRCTN15705531).

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Mediators of physical activity adherence: Results from an action control intervention in couples

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Abstract

Background: Behavior change interventions targeting self-regulation skills have generally shown promising effects. However, the psychological working mechanisms remain poorly understood.

Purpose: We examined theory-based mediators of a randomized controlled trial in couples targeting action control (i.e., continuously monitoring and evaluating an ongoing behavior). Self-reported action control was tested as the main mediating mechanism of physical activity adherence, and in addition self-efficacy and received social support from the partner.

Methods: Overweight individuals (*N*=121) and their heterosexual partners were randomly allocated to an intervention (information + action control text messages) or a control group (information only). Across a period of 28 days, participants reported on action control, self-efficacy, and received support in end-of-day diaries, and wore triaxial accelerometers to assess stable between-person differences in mediators and the outcome adherence to recommended daily activity levels (≥30 minutes of moderate activity in bouts of at least 10 minutes).

Results: On average, participants in the intervention group showed higher physical activity adherence levels, and higher action control, self-efficacy and received support compared to participants in the control group. Action control and received support emerged as mediating mechanisms, explaining 19.7% and 24.6% of the total intervention effect respectively in separate analyses, and 13.9% and 22.2% when analyzed simultaneously. No evidence emerged for self-efficacy as mediator.

Conclusions: Action control and received support partly explain the effects of an action control intervention on physical activity adherence levels. Continued research is needed to better understand what drives intervention effects to guide innovative and effective health promotion. (controlled-trials.com ISRCTN15705531)

Keywords: randomized controlled trial, mediation, physical activity, action control, self-efficacy, social support, couples

Mediators of physical activity adherence: Results of an action control intervention in couples

Regular physical activity has many benefits for health. Nevertheless, most individuals do not adhere to the recommended minimum level of activity (1). According to current guidelines, adults should accumulate at least 150 minutes of moderate activity throughout the week (or an equivalent combination of moderate and vigorous activity), performed in bouts lasting 10 or more minutes (2). Numerous studies have aimed at increasing physical activity in interventions, and have generally shown promising effects, albeit small in size (e.g., 3). However, to design effective interventions it is essential to understand *why* an intervention works (4). Within a randomized controlled design, mediation analysis provides the strongest possible inference as to what elements are causally responsible for achieving a desired outcome. Yet, in the context of physical activity, trials often do not analyze the mediating mechanisms by which interventions are successful (5), or do not use formal statistical tests of mediation (e.g., significance of the indirect effect through the mediator; 6). At the same time, theory-based interventions are needed to facilitate our understanding of the working mechanisms of a treatment (4, 7). Thus, this study aimed to examine the theoretically derived mediating mechanisms of an action control intervention in couples on physical activity adherence.

Self-regulation mechanisms in health behavior change

In systematic reviews, self-regulation constructs found most support for mediation in physical activity interventions (5, 7). In line with this, a recent review of obesity interventions (6) demonstrated that self-regulation skills (e.g., self-monitoring), along with autonomous motivation and self-efficacy were promising mediators of physical activity. Self-regulation describes various processes by which people pursue and attain goals and commonly it is distinguished between goal setting (i.e., determining which goals to pursue) and goal striving (i.e., planning and executing goal-promoting actions) (8). In theories of health behavior change, self-regulatory processes such as action planning or action control have been identified to

facilitate effective behavior change (e.g., Health Action Process Approach; 9). Action control refers to continuously monitoring and evaluating an ongoing behavior with regard to one's standards (10). Based on the principle of negative feedback control (11), it comprises the three subcomponents *awareness of standards* (i.e., being aware of one's set intentions), *self-monitoring* (i.e., observing one's behavior in order to evaluate whether it corresponds with one's intentions), and *self-regulatory effort* (i.e., applying means to reduce discrepancies between one's behavior and intentions). So far, interventions targeting action control (e.g., using self-monitoring diaries) among other self-regulatory processes were successful in changing physical activity behavior (12). The intervention effects were at least in part explained by changes in action control. Thus, the current literature provides preliminary evidence that action control is an effective strategy in changing physical activity behavior. Similarly, combining behavior change techniques consistent with control theory has recently been found most effective in improving physical activity (13). The present intervention study tested the effect of targeting action control comprehensively, and within the context of intimate couples.

There is evidence that improving self-regulatory skills such as planning and action control may result in more self-efficacy as an experimental side effect (14). Self-efficacy refers to beliefs in one's capability to perform the goal behavior by one's own actions and resources (15). One explanation for such an experimental side effect may be the experience of mastery, an important source of self-efficacy, that arises from successful behavior change. In line with this, 'prompting self-monitoring of behavioral outcome' has been identified as a significant behavior change technique for self-efficacy regarding physical activity in obese adults (16). So far, evidence on self-efficacy as a mediator of physical activity interventions is however mixed. Some studies showed support for self-efficacy as a significant psychosocial mediator (17), while others did not (18, 19).

Recently, studies have sought to involve close others into the self-regulation process of behavior change. For instance, jointly planning and enacting the behavior with a partner (i.e.,

collaborative implementation intentions) has been found effective (20). It is assumed that the involvement of a partner fosters social exchange processes such as the receipt of partner support that may in turn facilitate behavior change (21). Social support refers to the perceived availability of help or support actually received, and may be regarded as the provision or exchange of resources in times of need (22). Some studies support that interventions targeting close network members increased social network involvement such as social support, but did not test for mediation (23). Prestwich, Conner, Lawton, Ward, Ayres and McEachan (24) demonstrated that the effects of partner-based interventions were partially mediated by greater perceived social influence, partner support and enjoyment, but not intentions and self-efficacy. This preliminary evidence suggests that social support may serve as additional mediator in explaining effects of self-regulation interventions involving a close other. More research is needed that tests this assumption in other forms of dyadic regulation. Moreover, potential boundary conditions for the benefit of dyadic regulation via social support should be considered. For example, the role of social support may differ for men and women. The literature on social support indicates that women seem to be more skilled than men in providing effective support (25) and in timing support (26). Gender differences in the effectiveness of social support have also been found in the context of health behavior change, in that men benefitted more from social support in terms of their smoking (27) or dieting (28).

The present study

In sum, there is a need to formally test the mediators of behavior change interventions to elucidate the psychological working mechanisms, particularly those central to the driving theory. The present study contributes to this field by testing the theoretically derived and pre-registered mediating mechanisms of physical activity adherence in a recently published action control intervention. The *Dyadic Action Control Trial in overweight and obese Couples* (DYACTIC; 29) investigated the effectiveness of a theory-based action control intervention in promoting physical activity in overweight individuals, using action control text messages delivered in everyday life.

Moreover, by recruiting romantic couples as participants, it was possible to explore action control within a social context. The design of the trial combined accelerometer-based physical activity assessment and daily diaries during 28 consecutive days (14 days of intervention and 14 days of follow-up). As reported in detailed day-to-day analyses (30), the action control intervention effectively enhanced the daily adherence to physical activity recommendations during the intervention and follow-up phase, but no difference emerged in terms of daily moderate-to-vigorous activity (in minutes). Daily adherence to physical activity recommendation (≥ 30 minutes per day of moderate-to-vigorous physical activity, performed in bouts lasting 10 or more minutes) was operationalized based on the national guidelines at the time of the study (31), and was the main behavioral target of the intervention. No benefit of a dyadic version of the intervention (where partners were actively involved in the action control process) compared to an individual version (where partners also participated in the study) emerged.

The present study aims to understand the mechanisms that explain the intervention effect on the main behavioral target, adherence to recommended daily physical activity levels (objectively assessed via accelerometer). Given that the intervention effect was sustained across the intervention and follow-up phase (30), we were interested in explaining the stable difference in physical activity adherence between groups, and chose a between-person approach averaging mediators and outcomes across the 28 days. As proposed in the trial registration (ISRCTN15705531), we hypothesized that self-reported action control would serve as the main mediator of the intervention effect on physical activity adherence. Furthermore, it was assumed that the intervention would stimulate processes apart from action control, although it did not directly contain such elements. Previous research indicates that self-regulation interventions may increase self-efficacy (e.g., 14). Moreover, by involving the intimate partner with the same activity goals to participate in the study, the intervention may elicit social support from the partner (e.g., 24). Thus, we hypothesized that self-efficacy and received social support would serve as additional mediators of the intervention effect. In an exploratory analysis, we tested

whether the mediating pathway of social support would differ for men and women, assuming that men would benefit more from their female partner's support than women (25, 28).

Method

Participants

Heterosexual couples living in a committed relationship for at least 12 months and cohabitating for at least 6 months were recruited from the community via various channels (e.g., advertisements, flyers, research market institution). Both partners were overweight or obese (Body Mass Index [BMI] $\geq$ 25 kg/m^2), physically insufficiently active and intended to engage in regular physical activity. Random allocation to intervention (n = 61) and control group (n = 62) was based on a computer-generated allocation sequence using restricted randomization. 121 target persons (51.2% female) and their partners participated in the DYACTIC trial at baseline (see flowchart in Figure 1). Participants had an average age of 46.3 years (SD = 13.7, Range = 22-72), BMI of 31.1 (SD = 5.6, Range = 25-62) and relationship duration of 18.8 years (SD = 14.3, Range = 1-52). For more information on inclusion criteria and sampling procedure, please see Berli, Stadler, Inauen and Scholz (30). Randomization check did not yield significant group differences at baseline in terms of gender, marital status, education, employment status, age, body mass index, relationship duration, action control and received social support (all ps > .05). However, significant differences emerged in terms of physical activity intention ($M/SD_{\text{Intervention}}$ = 4.82/0.57; M/SD_{Control} = 4.57/0.69) and self-efficacy ($M/SD_{\text{Intervention}}$ = 4.98/0.61; M/SD_{Control} = 4.70/0.72). Sensitivity analyses including baseline intention and self-efficacy as covariates did not support that these initial differences accounted for variation in the outcomes. The present analyses are based on a final sample of 119 target persons, as two participants did not provide any data on the accelerometer-based outcome measure.

Design

The study was part of a single-blind randomized controlled trial (ISRCTN15705531) funded by the Swiss National Science Foundation (PP00P1_133632/1). It comprised a baseline

assessment and 28-day diary period, of which the intervention took place within the first 14 days followed by another 14 days of assessment-only. At baseline, participating couples provided written consent, completed an online questionnaire and were handed out study smartphones and accelerometers for a diary period of 28 consecutive days starting the day after baseline. Participants were instructed to fill in a short electronic end-of-day diary on the study smartphone within one hour of going to bed, and not to discuss their answers with their partners. They were asked to wear the accelerometer continuously during waking hours at the hip on the side of their dominant hand. The study was approved by the review board of the University of Bern, Switzerland. A more detailed description of the DYACTIC trial can be obtained in the published study protocol (29).

Experimental conditions

Intervention group. The action control intervention consisted of three parts: 1) an information leaflet with recommendations on health-enhancing physical activity at the time of the study, which involved to engage in at least 30 minutes of moderate-to-vigorous physical activity per day performed in bouts of at least 10 minutes (31); 2) setting specific behavioral goals to achieve the recommended physical activity level; and 3) one action control text message sent every weekday across the first 14 diary days at random times during the working day (resulting in a total of 10 messages). Each text message targeted one of the three components of action control (awareness of standards, self-monitoring, self-regulatory effort) and differed in content (for an overview of all messages see 29). Table 1 summarizes the intervention components in terms of the BCT taxonomy (32). An experimental variation in the intervention group involved a dyadic delivery for half of the participants (partner were instructed to assist target persons in setting behavioral goals, and to send the text messages in a personalized form but with the exact same content), and an individual delivery for the other half of the participants (target persons set their behavioral intentions individually, and text messages were sent from the study staff via an automated system).

Control group. Participants of the control group received the same information leaflet, but were not asked to set specific behavioral intentions. They received text messages at the same time as participants in the intervention group, but with a reminder to fill in the end-of-day diary.

Measures

Outcome. *Physical activity adherence* was assessed with triaxial GT3X+ monitors (ActiGraph, Pensacola, FL) and processed in ActiLife 6 software. Only days with at least 10 hours of valid wear time were included in the analyses, with non-wear time filtered based on an algorithm of ≥ 90min of consecutive zeros in vector magnitude (33). Across the 119 target persons in the final sample, 2854 (85.7%) days were available. To identify physical activity of at least moderate intensity, cut-points by Sasaki, John and Freedson (34; > 2690 cpm in vector magnitude) were used. Based on physical activity recommendations, a bout analysis was conducted summing the total minutes of moderate physical activity per day that was performed in bouts of at least 10 minutes (ten consecutive minutes of observations had to exceed the moderate intensity cut-point, allowing a maximum of two observations to fall below during that period). Days with 30 or more minutes were coded as 1 (adherent days), days with less than 30 minutes were coded as 0 (non-adherent days). To obtain a stable between-person score of physical activity adherence, which served as the main outcome for the present analyses, the mean of adherent (=1) and non-adherent (=0) days across the 28-day period was calculated for each person.

Mediators. The end-of-day-diary contained measures of action control, self-efficacy and received social support from the partner, with a response format of 1 (today not at all true) to 6 (today completely true). Missings were overall low, with n = 3112 [93.4%] of 3332 possible diary days available across the 119 participants. To obtain stable between-person scores, person-specific means across the 28 days were computed for each mediator. A between-person reliability index R_{kf} (35) was calculated for the action control and social support scales, which indicates whether someone tends to be high or low on a given scale.

Action control was assessed with three items that were combined into a mean score (adapted from 36): “Today I had my intentions in terms of my physical activity constantly on my mind” for *awareness of standards*, “Today I constantly monitored whether I acted the way I intended to in terms of my physical activity“ for *self-monitoring*, and “Today I did my best to be physically active the way I intended to” for *self-regulatory effort* (R_{kf} = .99).

Self-efficacy was assessed with a single item (adapted from 37): “I am confident that I can be physically active tomorrow even if it is difficult.“

Received social support from partner was assessed with two items that were combined into a mean score (adapted from 38): “Today, I received *emotional* support from my partner in terms of my physical activity“ (e.g., comfort or encouragement), and “Today, I received *practical* support from my partner in terms of my physical activity“ (e.g., advice or information) (R_{kf} = .99). Before answering the items, participants were presented with a short description and some examples of emotional and practical support.

Baseline characteristics. At baseline, questionnaires included composite measures of action control (nine items adapted from 36), self-efficacy (four items adapted from 37) and received social support from partner (ten items adapted from 39). Also, socio-demographic variables such as gender, age and BMI were assessed.

Analytical Procedure

We examined action control, self-efficacy and received social support as separate mediators of the intervention effect on physical activity adherence. We used regression procedures in line with recommendations for appropriate mediation analysis (40): We first tested the effect of the intervention on the mediator (action theory test, or *a* coefficient) by regressing the mediator on intervention group. Second, we tested the effect of the mediator on the outcome (conceptual theory test, or *b* coefficient) by regressing the outcome simultaneously on the mediator and intervention group (the latter resulting in the direct effect, or *c’* coefficient). Third, we calculated strength and significance of the indirect effect following the product of coefficients approach

using bias-corrected bootstrapping with 10000 resamples (41). As an effect size measure, we indicated the ratio of the indirect to the total effect as the proportion mediated, and set the lower and upper bound to be 0.0 and 1.0 respectively (42). Analyses included gender and device wear-time as covariates, as well as baseline measure of the respective mediator to account for any variance in mediator and outcome due to differences at baseline. We used the same set of covariates for all regression analyses (see 43). For a meaningful intercept, all continuous variables were centered at the sample mean (i.e. grand-mean centering). In addition to the single mediator models, we tested a multiple mediator model specifying action control, self-efficacy, and received social support simultaneously as mediators. This allowed determining their independent contribution in explaining the intervention effect on the outcome while adjusting for the other mediators (i.e. specific indirect effects; 44). The same regression procedures were used as described above, and analyses included gender, device wear-time and baseline measures of all mediators as covariates.

To examine potential gender differences of the mediation via received social support, we conducted a moderated mediation analysis. We included an interaction term with gender in each regression analysis to test whether the effect was different for women (coded as 1) compared to men (coded as 0). As such, for the action theory test social support was regressed on intervention group, gender and the interaction between intervention group and gender. For the conceptual theory test, the outcome was regressed on social support, gender, the interaction between social support and gender, intervention group and the interaction between intervention group and gender. Device wear-time and baseline measure of received social support were again included as covariates. We then calculated the indirect effect of the mediator conditionally at each value of the moderator (men and women) and tested these conditional indirect effects subsequently for equality as an index of moderated mediation. All analyses were implemented using the PROCESS macro in SPSS 23 (version 2.13) (43). We reported regression coefficients and 95%

confidence intervals as indicators of variability in the text. For complete results see tables 1 through 5 in the supplemental material.

Results

Descriptives

Figure 2 displays the mean levels of action control, self-efficacy and received social support across the 28 diary days separately for the intervention and the control group. For all three mediators, a robust mean difference between the intervention and control group emerged from the first intervention day on, and was sustained across the 14 days of intervention and the 14 days of follow-up. A corresponding pattern was found for the outcome, with a stable difference in adherence to recommended daily activity levels between the two groups over the course of the intervention and follow-up phase (for details see 30). No differential time trends across the two groups or the two phases were found for none of the variables of interest. Table 1 displays the means of the outcome and all three mediators that were aggregated across the 28 days to capture the stable between-person differences in the two groups.

Moreover, bivariate associations between the outcome, the three mediators and socio-demographic variables were analyzed (see Table 2). Physical activity adherence had positive, but small associations with action control, self-efficacy and social support (r = .16 - .24), and correlated positively with gender. Among the three mediators, social support was moderately associated with action control and self-efficacy (r = .45 - .49), and action control and self-efficacy were strongly correlated (r = .72).

Total intervention effect on physical activity adherence

The total effect of the action control intervention on physical activity adherence was B = 0.122 ($p < .01$), with a 95%-confidence interval [CI] ranging from 0.045 to 0.199. This indicates that the mean level of physical activity adherence across the 28 days was around 12% higher in the intervention group compared to the control group. While participants of the control groups adhered to the recommended daily activity levels (≥ 30 minutes per day of moderate-to-vigorous

physical activity, performed in bouts lasting 10 or more minutes) on average on 22% of the days across the 28-day diary period (corresponding with around 6 out of 28 days), participants of the intervention group adhered on average on 34% of the days (corresponding with around 9.5 out of 28 days).

Action control as mediator of physical activity adherence

Figure 3A depicts the results from the main mediation analysis for action control. Regression analyses were adjusted for gender, device wear-time and baseline action control. A significant positive effect of the intervention on action control emerged ($B = 0.472$, $p < .001$, [0.220, 0.723]). Action control marginally predicted physical activity adherence over and above the effect of group ($B = 0.051$, $p = .074$, [-0.005, 0.107]). There was a significant indirect effect of the intervention on physical activity adherence through action control ($B = 0.024$, [0.001, 0.061]). The mediated effect explained 19.7% [0.004, 0.743] of the total effect of the intervention on the outcome. The direct effect of the intervention on physical activity adherence remained significant when accounting for action control ($B = 0.098$; $p < .05$ [0.017, 0.178]).

Additional mediators: Self-efficacy and received social support

Adjusting for gender, device wear-time and baseline self-efficacy, the intervention showed a significant positive effect on self-efficacy ($B = 0.591$, $p < .001$, [0.319, 0.863]). Self-efficacy did not predict physical activity adherence over and above the effect of group ($B = 0.024$, $p = .362$, [-0.028, 0.077]). No significant indirect effect of the intervention on physical activity adherence through self-efficacy emerged ($B = 0.014$, [-0.015, 0.050]). The mediated effect explained 12.0% [0.000, 0.596] of the total intervention effect. The direct effect of the intervention on physical activity adherence remained significant when accounting for self-efficacy ($B = 0.106$, $p < .05$, [0.023, 0.190]).

Adjusting for gender, device wear-time and baseline social support, the intervention showed a significant positive effect on received social support ($B = 0.516$, $p < .001$, [0.224, 0.808]). Received social support positively predicted physical activity adherence over and above the

effect of group (B = 0.059, p < .05, [0.011, 0.107]). A significant indirect effect of the intervention on physical activity adherence through received social support emerged (B = 0.030 [0.007, 0.071]). The mediated effect explained 24.6% [0.060, 0.805] of the total intervention effect. The direct effect of the intervention on physical activity adherence remained significant when accounting for received social support (B = 0.093; p < .05, [0.015, 0.172]). Results are depicted in Figure 3B.

Multiple mediator model

Next, we simultaneously tested action control, self-efficacy, and received social support as mediators of physical activity adherence. Due to the moderate to high overlap in constructs, the independent contributions of the mediators resulted in somewhat attenuated mediated effects compared to the single mediator models. The specific indirect effect via action control (B = 0.017, [-.011, 0.060]) explained 13.9% of the total intervention effect, and via received social support 22.2% (B = 0.027, [0.001, 0.072]). No specific indirect effect via self-efficacy was found (B = -0.010, [-.052, 0.021]). The direct effect of the intervention on physical activity adherence remained significant when accounting for the three mediators (B = 0.087; p < .05, [0.002, 0.171]). Although the significance for the mediated effect via action control was compromised, the point estimates for action control and received social support were negligibly reduced. The multiple mediator model overall supported the pattern of results from the single mediator models. For the interested readers, we visually illustrated the mediated effects with violin plots displaying the sampling distribution of the indirect effect for each mediator (see Figure S1 in the supplemental material).

Exploring the role of gender: A moderated mediation model for social support

In an additional exploratory analysis, we tested the assumption that the mediation via social support would differ between men and women. As noted previously (30), gender did not emerge as a significant moderator of the overall intervention effect as initially hypothesized (see trial registration ISRCTN15705531). However, we found support for a moderated mediation model

for received social support (for complete results see table S4 in the supplemental material): In men, the intervention significantly increased received social support (B = 0.807, p < .001, [0.391, 1.224]), and received social support was positively associated with physical activity adherence (B = 0.108, p < .01, [0.040, 0.177]). These associations were less pronounced for women. The conditional indirect effect of the intervention on physical activity adherence through received social support was only significant for men (B = 0.087 [0.024, 0.200]), but not for women (B = 0.005 [-0.006, 0.040]), and significantly differed from each other (B = -0.083 [-0.195, -0.016]).

Discussion

A critical step in advancing our understanding of health behavior change is to identify the causal mechanisms of interventions using formal mediation. This study contributed to this field by testing theory-based mediators of an action control intervention in couples. Results showed that participants of the intervention group had a higher average level of physical activity adherence across the 28 days of the diary period compared to participants of the control group (34% vs. 22%). The intervention also resulted in higher mean levels of action control, self-efficacy and received social support across the 28 days. Participants' increased use of action control strategies provide evidence that the experimental manipulation of action control was successful as intended. It suggests that text messaging is a promising mean to target action control comprehensively. The present findings also show that the action control intervention increased social support from the partner. This is in line with previous findings that an intervention involving a close other can elicit support received from this partner (24). Moreover, it goes along with literature suggesting that self-regulation does not occur in isolation from others and is closely linked with interpersonal processes (45). The present findings show preliminary support that self-regulation may elicit positive social interactions. More research is however needed to further elucidate how this process works. Were partners actively providing support as a supplement to the action control text messages or were participants actively mobilizing support from their partners?

Findings further suggest that the increased levels of action control and received social support at least in part affected how well participants repeatedly adhered to the physical activity recommendations across the 28 diary days (i.e. engaging daily in at least 30 minutes of moderate-to-vigorous physical activity performed in bouts of at least 10 minutes). When tested separately, action control and received support from the partner emerged as mediating mechanisms, explaining 19.7% and 24.6% of the total intervention effect respectively. This pattern of results was overall maintained when all mediators were considered simultaneously in a multiple mediator analysis. The mediated effects of action control and received social support were somewhat attenuated in size, explaining 13.9% and 22.2% of the total intervention effect respectively. We did not find any evidence for self-efficacy as a mediator of physical activity adherence. As Preacher & Hayes (2008) point out, the effects of mediators are often attenuated to the degree to which they are correlated. Because in interventions the mediators are almost necessarily correlated due to their common cause, the mediators' independent contribution (i.e., specific indirect effect) may not be large. This can also compromise statistical significance, as was the case for action control. Assuming that in everyday life the proposed mediators do not occur in isolation, the main interest of the present study was not to contrast the relative magnitude of the independent effect of the different mediators. For example, support from the partner via encouragement is likely to stimulate self-efficacy beliefs (46), reminding on scheduled activities will likely result in higher support and action control (i.e. subfacet awareness of standards), monitoring progress as part of action control (i.e. subfacet self-monitoring) will likely elicit feelings of mastery, resulting in higher self-efficacy etc. The common process of action control, self-efficacy, and received support that is manifested in their conceptual overlap, may thus also provide a unique contribution to explaining part of the effects on physical activity adherence.

Overall, the current study adds to the existing mixed findings on mediators in physical activity interventions, particularly with regard to self-efficacy (e.g., 18). It provides some support

for evidence from previous literature on self-regulation (e.g., 6, 12) and social support (e.g., 17) as mediators of physical activity interventions. Small mediation effects are not unusual in behavior change interventions (cf. 24) and our results compare to studies reporting mediation of around 20% of the total intervention effect (e.g., 47). Further, it is not unusual for studies to report no significant mediation effect of psychological variables at all, mostly due to the lack of change in mediators (e.g., 19, 48, 49). It is however important that such results are reported too, as they contribute equally to our understanding of the effectiveness of behavioral interventions. Potential explanations for the difficulty to establish mediation involve that a) interventions are often not adequately powered to examine mediation (18), b) mechanisms may have underlying moderating factors (19), and c) intervention effects may occur due to non-specific factors other than the theoretically derived factors (50). In the present study, we could rule out a number of potential alternative explanations like differences in interviewer, device wear-time compliance, baseline measures or third variables that could serve as confounders of the intervention effect.

Across all three mediators, particularly self-efficacy, associations with the outcome were comparably weak. This is in contrast to the theoretical predictions and empirical evidence of the HAPA model on the role of action control and self-efficacy specifically for physical activity behavior (36). Also, self-efficacy has been identified as one of the most consistent correlates of physical activity in adults (51). What are the reasons for the attenuated associations? With regard to self-efficacy, one possible explanation is that it may not be consistently effective across different populations. A recent meta-analysis could for example not establish a significant relationship between self-efficacy and physical activity in obese adults (16), suggesting that in this specific population other mechanisms might be more relevant for increasing levels of physical activity. One could also argue that the measure of self-efficacy we used (i.e., confidence to be physically active in general) was not sufficient to detect an association with the behavior itself. Previous research proposed the distinction in phase-specific self-efficacy beliefs and showed that for behavior itself, maintenance self-efficacy (i.e. confidence to maintain the newly

adopted activity behavior) and recovery self-efficacy (i.e. confidence to resume physical activity after a setback) seem to be particularly predictive (52). Further, the present intervention was not designed to specifically target self-efficacy. Thus, it is possible that self-efficacy was stimulated as an experimental side effect rather than a causal process of changes in physical activity adherence. A more general explanation for the weak associations of the mediators and outcome could lie in the measurement of physical activity. While most previous work employed self-report measures of physical activity, the present study used an accelerometer-based objective outcome. This may reduce potential bias in self-report measures due to shared method variance, social desirability or reactive responding (accelerometer did not provide feedback on whether participants achieved the recommended physical activity levels). Recent studies for example reported less consistent associations between social support and self-efficacy with physical activity based on accelerometer-assessed compared to self-reported measures (53).

In an exploratory analysis, we tested the assumption that the mediating pathway via social support may be more pronounced for men than women, as research suggests that women are more skilled in providing effective support (25). Our findings provide preliminary support for a moderated mediation, in that the indirect effect via social support was only significant for men but not for women. In men, the intervention increased levels of received social support, and higher mean levels were also predictive of higher physical activity adherence. One possible interpretation of this finding is that women are more responsive to their partners' need (cf. 26) and might thus actively provide more support and more adequate support to their male partners in response to the action control reminders. In line with this, previous research indicated higher empathic accuracy in women (e.g., 54). Importantly, we ruled out the possibility that these differential effects were attributed to the fact that baseline social support levels differed between men and women or that there was a ceiling effect for women so that women had no room for improvement through the intervention.

Strengths and Limitations

The present study has several strengths and contributions to the current literature. It involves a formal test of mediation in an intervention designed to target specific theoretically derived and pre-registered psychological working mechanisms. It employed an objective measure for the main outcome physical activity adherence. This avoids shared measurement variance between mediators and outcome that may lead to an overestimation of effects with self-reported mediators and outcomes (55). Moreover, the assessment methods of the mediators (daily diaries) and the outcome (accelerometer) in daily life has the advantages of increasing ecological validity and minimizing systematic bias in recall due to the short interval (56). This gives us a most precise measure possible of the psychological mediators and outcome at the between-person level (35). The following limitations need to be acknowledged as well. First, to keep the daily questionnaire short and participant burden low, self-efficacy was assessed with a single item. This precluded us from performing a reliability analysis. Given that self-efficacy correlated positively with the other mediators, the single item still seems to serve as a useful and valid measure. While the high correlation between self-efficacy and action control makes it difficult to empirically distinguish the constructs, this does not necessarily mean that the validity of the measures is weak, but rather indicates that these two volitional processes are highly intertwined in daily life. Second, our results indicate that compared to existing literature, the mediators still explain a sizeable amount of the total intervention effect on physical activity adherence. Yet, the conceptual theory test (b paths) only achieved statistical significance for social support, but not for the main mediator action control. Future studies should consider using larger samples with greater power to detect and compare these mediation paths with more precision. Third, assuming that the mediation is a fast occurring process (e.g., within the same day), we assessed mediators and behavior at a daily level. This however does not ascertain temporal order (i.e., whether the change in mediators occurred *before* the change in behavior). To establish a causal effect of the mediator, future research needs to consider the possibility to randomly assign values of the mediator (e.g., double randomization; 57). Following an action control intervention individuals could for example be

re-randomized to a self-efficacy or social support intervention to experimentally test a causal chain design. Moreover, future studies should consider using within-person intervention designs (e.g., persons receiving action control text messages on randomly selected days, but not on other days). This would enable to zoom in on the temporal process of the causal effect, and test whether action control text messages have immediate or lagged effects on the mediator and outcome. So far, the standard analytic procedures in between-person intervention designs test mediation strictly at the between-person level (58). Although there is some controversy around this topic (59), alternative analytic approaches using within-person information, particularly in the longitudinal multilevel context, have not yet been established.

Conclusions

The present study adds to the growing literature on mediating mechanisms of physical activity interventions by identifying important mediators of an action control intervention in couples. In summary, this study suggests that text messages can be used to affect our self-regulation skills such as action control (e.g., keeping one's goals in mind, monitoring one's behavior and exerting effort to achieve one's goals), as well as our social interactions with close others (e.g., social support from partner) in daily life. This can at least in part promote better adherence to recommended daily activity levels. However, given that the mechanisms are often intertwined in daily life, establishing unique mediator effects is difficult. Uncovering the working mechanisms of effective interventions is of significant relevance for designing innovative and effective health promotion programs in the future. However, more research is needed to understand what apart from theoretically derived constructs drive these effects. Moreover, researchers need to continue to examine the conceptual theory link using sound methodologies (e.g., objective parameters of behaviors), and to carefully think about for whom and how a powerful effect on a proposed mechanism can be achieved.

References

1. Hallal PC, Andersen LB, Bull FC, et al.: Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet.* 2012, *380:*247-257.
2. World Health Organization [WHO]: *Physical activity. Fact Sheet.* Retrieved June 27, 2016 from http://www.who.int/mediacentre/factsheets/fs385/en/
3. Hillsdon M, Foster C, Thorogood M: Interventions for promoting physical activity. *Cochrane Database of Systematic Reviews.* 2005, *1*.
4. Baranowski T, Anderson C, Carmack C: Mediating variable framework in physical activity interventions. How are we doing? How might we do better? *Am J Prev Med.* 1998, *15:*266-297.
5. Rhodes RE, Pfaeffli LA: Mediators of physical activity behaviour change among adult non-clinical populations: a review update. *International Journal of Behavioral Nutrition Physical Activity.* 2010, *7:*37.
6. Teixeira PJ, Carraca EV, Marques MM, et al.: Successful behavior change in obesity interventions in adults: A systematic review of self-regulation mediators. *BMC Med.* 2015, *13:*84.
7. Lewis BA, Marcus BH, Pate RR, Dunn AL: Psychosocial mediators of physical activity behavior among adults and children. *Am J Prev Med.* 2002, *23:*26-35.
8. Mann T, de Ridder D, Fujita K: Self-regulation of health behavior: social psychological approaches to goal setting and goal striving. *Health Psychology.* 2013, *32:*487-498.
9. Schwarzer R: Modeling health behavior change: How to predict and modify the adoption and maintenance of health behaviors. *Applied Psychology: An International Review.* 2008, *57:*1-29.
10. Sniehotta FF, Nagy G, Scholz U, Schwarzer R: The role of action control in implementing intentions during the first weeks of behaviour change. *British Journal of Social Psychology.* 2006, *45:*87-106.
11. Carver CS, Scheier MF: *On the self-regulation of behavior*. Cambridge, UK: Cambrigde University Press, 1998.
12. Fleig L, Lippke S, Pomp S, Schwarzer R: Intervention effects of exercise self-regulation on physical exercise and eating fruits and vegetables: A longitudinal study in orthopedic and cardiac rehabilitation. *Prev Med.* 2011, *53:*182-187.
13. Prestwich A, Conner M, Hurling R, Ayres K, Morris B: An experimental test of control theory-based interventions for physical activity. *British Journal of Health Psychology.* in press.

14. Scholz U, Ochsner S, Luszczynska A: Comparing different boosters of planning interventions on changes in fat consumption in overweight and obese individuals: A randomized controlled trial. *International Journal of Psychology.* 2013, *48:*604-615.
15. Bandura A: Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review.* 1977, *84:*191-215.
16. Olander EKO, Fletcher H, Williams S, et al.: What are the most effective techniques in changing obese individuals' physical activity self-efficacy and behaviour: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity.* 2013, *10:*1-15.
17. Anderson ES, Winett RA, Wojcik JR, Williams DM: Social cognitive mediators of change in a group randomized nutrition and physical activity intervention: social support, self-efficacy, outcome expectations and self-regulation in the guide-to-health trial. *J Health Psychol.* 2010, *15:*21-32.
18. Lewis BA, Williams DM, Martinson BC, Dunsiger S, Marcus BH: Healthy for life: a randomized trial examining physical activity outcomes and psychosocial mediators. *Annals of Behavioral Medicine.* 2013, *45:*203-212.
19. Plotnikoff RC, Pickering MA, Rhodes RE, Courneya KS, Spence JC: A test of cognitive mediation in a 12-month physical activity workplace intervention: Does it explain behaviour change in women? *International Journal of Behavioral Nutrition and Physical Activity.* 2010, *7:*32.
20. Prestwich A, Conner MT, Lawton R, et al.: Randomized controlled trial of collaborative implementation intentions targeting working adults' physical activity. *Health Psychology.* 2012, *31:*486-495.
21. Burkert S, Scholz U, Gralla O, Roigas J, Knoll N: Dyadic planning of health-behavior change after prostatectomy: A randomized-controlled planning intervention. *Social Science & Medicine.* 2011, *73:*783-792.
22. Schwarzer R, Knoll N: Social support. In D. French, K. Vedhara, A. A. Kaptein and J. Weinman (eds), *Health Psychology*. Malden, MA: Blackwell, 2010, 283-293.
23. Sorkin DH, Mavandadi S, Rook KS, et al.: Dyadic collaboration in shared health behavior change: The effects of a randomized trial to test a lifestyle intervention for high-risk Latinas. *Health Psychology.* 2014, *33:*566-575.
24. Prestwich A, Conner MT, Lawton RJ, et al.: Partner- and planning-based interventions to reduce fat consumption: Randomized controlled trial. *British Journal of Health Psychology.* 2014, *19:*132-148.

25. Cutrona CE: *Social support in couples*. Thousand Oaks, CA: Sage, 1996.
26. Neff LA, Karney BR: Gender differences in social support: A question of skill or responsiveness? *Journal of Personality and Social Psychology.* 2005, *88:*79-90.
27. Carlson LE, Goodey E, Bennett MH, Taenzer P, Koopmans J: The addition of social support to a community-based large-group behavioral smoking cessation intervention: Improved cessation rates and gender differences. *Addictive Behaviors.* 2002, *27:*547-559.
28. Scholz U, Ochsner S, Hornung R, Knoll N: Does social support really help to eat a low-fat diet? Main effects and gender differences of received social support within the Health Action Process Approach. *Applied Psychology: Health and Well Being.* 2013, *5:*270-290.
29. Scholz U, Berli C: A Dyadic Action Control Trial in Overweight and Obese Couples (DYACTIC). *BMC Public Health.* 2014, *14:*1321.
30. Berli C, Stadler G, Inauen J, Scholz U: Action control in dyads: A randomized controlled trial to promote physical activity in everyday life. *Social Science & Medicine.* 2016, *163:*89-97.
31. Bundesamt für Sport [BASPO], Bundesamt für Gesundheit [BAG], Gesundheitsförderung Schweiz, Netzwerk Gesundheit und Bewegung Schweiz: *Gesundheitswirksame Bewegung [Health-enhancing physical activity]*. Magglingen: BASPO, 2009.
32. Michie S, Richardson M, Johnston M, et al.: The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine.* 2013, *46:*81-95.
33. Choi L, Liu Z, Matthews CE, Buchowski MS: Validation of Accelerometer Wear and Nonwear Time Classification Algorithm. *Medicine & Science in Sports & Exercise.* 2011, *43:*357-364.
34. Sasaki JE, John D, Freedson PS: Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport.* 2011, *14:*411-416.
35. Cranford JA, Shrout PE, Iida M, et al.: A procedure for evaluating sensitivity to within-person change: Can mood measures in diary studies detect change reliably? *Personality and Social Psychology Bulletin.* 2006, *32:*917-929.
36. Scholz U, Nagy G, Schüz B, Ziegelmann JR: The role of motivational and volitional factors for self-regulated running training: Associations on the between- and within-person level. *British Journal of Social Psychology.* 2008, *47:*421-439.
37. Sniehotta FF, Scholz U, Schwarzer R: Bridging the intention-behaviour gap: Planning, self-efficacy, and action control in the adoption and maintenance of physical exercise. *Psychology & Health.* 2005, *20:*143-160.

38. Bolger N, Zuckerman A, Kessler RC: Invisible support and adjustment to stress. *Journal of Personality and Social Psychology.* 2000, *79:*953-961.
39. Schulz U, Schwarzer R: Soziale Unterstützung bei der Krankheitsbewältigung: Die Berliner Social Support Skalen (BSSS). *Diagnostica.* 2003, *49:*73-82.
40. Cerin E, Mackinnon DP: A commentary on current practice in mediating variable analyses in behavioural nutrition and physical activity. *Public Health Nutr.* 2009, *12:*1182-1188.
41. Mackinnon DP, Lockwood CM, Williams J: Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivariate Behavioal Research.* 2004, *39:*99 - 128.
42. Shrout PE, Bolger N: Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods.* 2002, *7:*422-445.
43. Hayes AF: *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach.*: Guilford Press, 2013.
44. Preacher KJ, Hayes AF: Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavioral Research Methods.* 2008, *40:*879-891.
45. Fitzsimons GM, Finkel EJ: Interpersonal influences on self-regulation. *Current Directions in Psychological Science.* 2010, *19:*101-105.
46. Banik A, Luszczynska A, Pawlowska I, et al.: Enabling, not cultivating: Received social support and self-efficacy explain quality of life after lung cancer surgery. *Annals of Behavioral Medicine.* 2017, *51:*1-12.
47. Fuemmeler BF, Masse LC, Yaroch AL, et al.: Psychosocial mediation of fruit and vegetable consumption in the body and soul effectiveness trial. *Health Psychology.* 2006, *25:*474-483.
48. Opdenacker J, De Bourdeaudhuij I, Auweele YV, Boen F: Psychosocial mediators of a lifestyle physical activity intervention in women. *Psychology of Sport and Exercise.* 2009, *10:*595-601.
49. Baruth M, Wilcox S, Blair S, et al.: Psychosocial mediators of a faith-based physical activity intervention: Implications and lessons learned from null findings. *Health Education Research.* 2010, *25:*645-655.
50. Donovan HS, Kwekkeboom KL, Rosenzweig MQ, Ward SE: Nonspecific effects in psychoeducational intervention research. *West J Nurs Res.* 2009, *31:*983-998.
51. Bauman AE, Reis RS, Sallis JF, et al.: Correlates of physical activity: Why are some people physically active and others not? *The Lancet.* 2012, *380:*258-271.

52. Scholz U, Sniehotta FF, Schwarzer R: Predicting physical exercise in cardiac rehabilitation: The role of phase-specific self-efficacy beliefs. *Journal of Sport & Exercise Psychology.* 2005, *27:*135-151.
53. Van Dyck D, Cardon G, Deforche B, et al.: Environmental and psychosocial correlates of accelerometer-assessed and self-reported physical activity in Belgian adults. *International Journal of Behavioral Medicine.* 2011, *18:*235-245.
54. Thomas G, Fletcher GJ: Mind-reading accuracy in intimate relationships: Assessing the roles of the relationship, the target, and the judge. *Journal of Personality and Social Psychology.* 2003, *85:*1079-1094.
55. Sallis JF, Taylor WC, Dowda M, Freeson PS, Pate RR: Correlates of vigorous physical activity for children in grades 1 through 12: Comparing parent-reported and objectively measured physical activity. *Pediatric Exercise Science.* 2002, *14:*30-44.
56. Heron KE, Smyth JM: Ecological momentary interventions: Incorporating mobile technology into psychosocial and health behaviour treatments. *British Journal of Health Psychology.* 2010, *15:*1-39.
57. MacKinnon DP, Pirlott AG: Statistical approaches for enhancing causal interpretation of the M to Y relation in mediation analysis. *Personality and Social Psychology Review.* 2015, *19:*30-43.
58. Preacher KJ: Advances in mediation analysis: A survey and synthesis of new developments. *Annual Review of Psychology.* 2015, *66:*825-852.
59. Pituch KA, Stapleton LM: Distinguishing between cross- and cluster-level mediationprocesses in the cluster randomized trial. *Sociological Methods & Research.* 2012, *41:*630-670.

Table 1

Overview of intervention components and corresponding behavior change techniques (32)

Intervention components	**Behavior change techniques (BCT's)**
Information leaflet on benefits and recommendations of physical activity for adults	Information about health consequences
Specifying behavioral intentions to achieve the minimum recommendation	Goal setting
10 text messages targeting subfacets of action control (awareness of standards, self-monitoring, self-regulatory effort)	Self-monitoring of behavior Discrepancy between current behavior and goal standard
Daily diary across 28 days	Self-monitoring of behavior

Table 2

Descriptive statistics for intervention (n = 58) and control group (n = 61) and between-person correlations across both groups

	Control Group	*Intervention Group*	1	2	3	4	Gender	Age	BMI
1. Physical activity adherence			-	.21*	.16†	.24*	-.18*	-.03	-.13
M	.22	.34							
SD	.19	.24							
Range	.00 - .84	.00 - .82							
2. Action control				-	.72**	.49**	.23*	.20*	-.03
M	3.18	3.72							
SD	0.86	0.65							
Range	1.44 - 5.01	1.97 - 4.88							
3. Self-efficacy					-	.45**	.20*	.19*	.01
M	3.72	4.37							
SD	0.89	0.61							
Range	1.65 - 5.50	1.90 - 5.09							
4. Received social support						-	.18†	.21*	-.10
M	2.46	3.04							
SD	0.94	0.77							
Range	1.00 - 4.39	1.40 - 4.29							

Note. BMI = Body Mass Index; Gender is coded as 0 = male and 1 = female. $^{\dagger}p < .10$, *p < .05, **p < .01

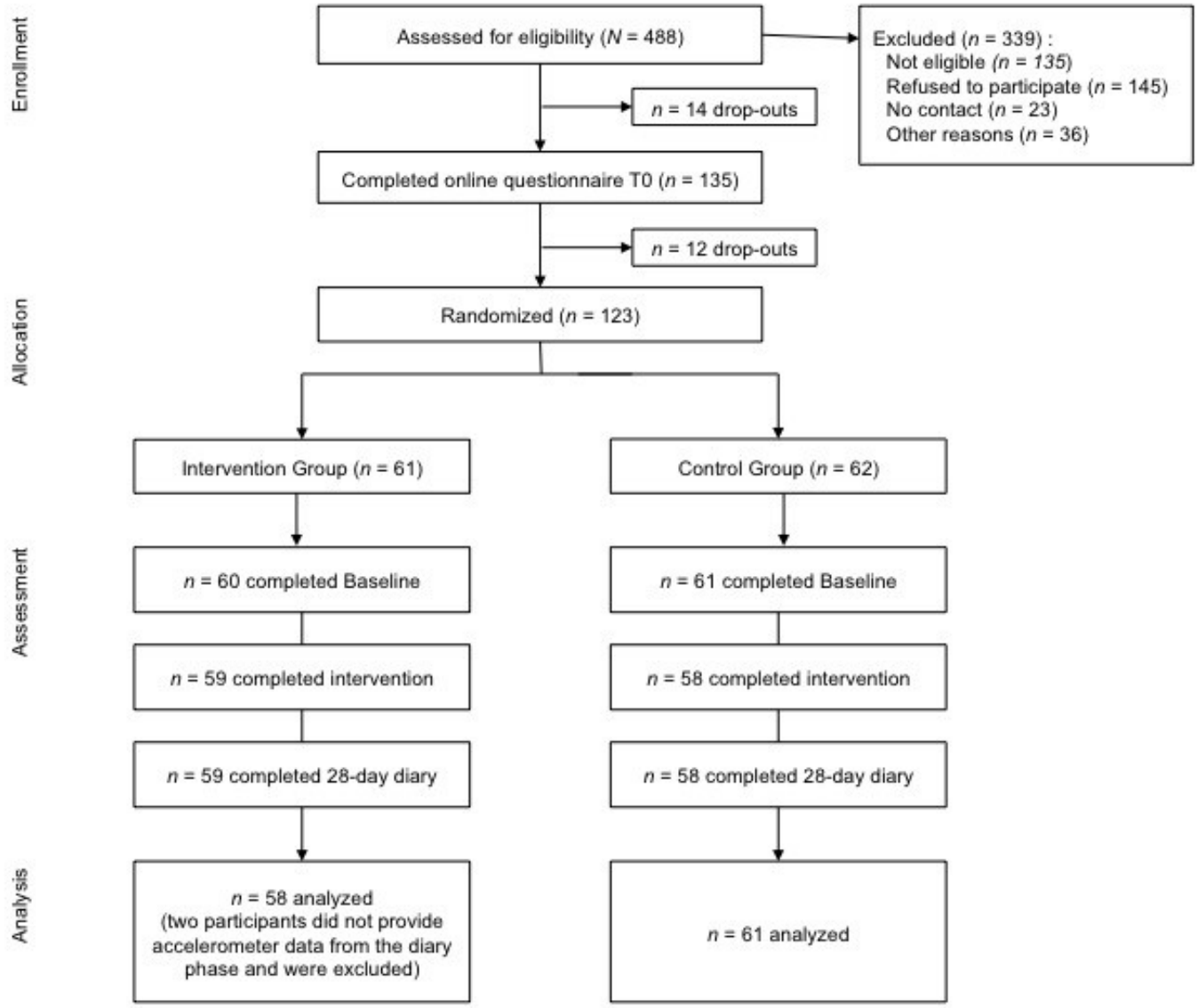

Figure 1 Flowchart of participating couples.

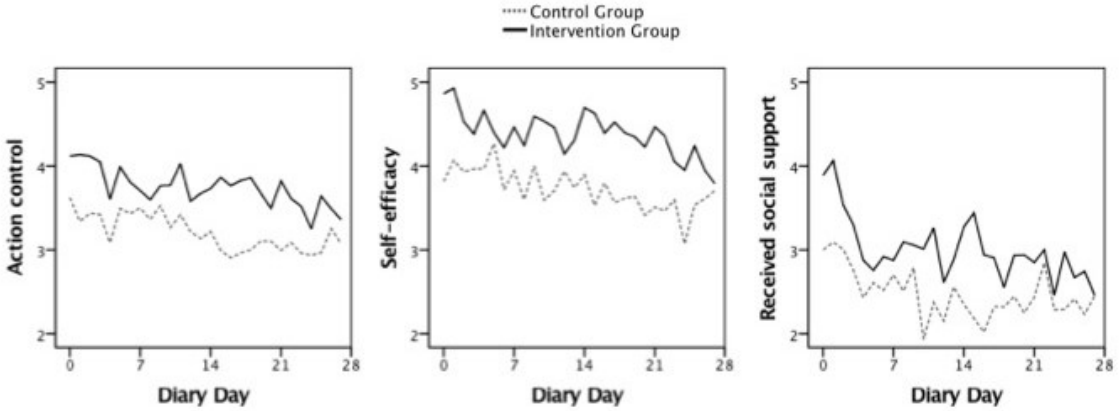

Figure 2 Mean levels of mediators across the 28 diary days displayed for the intervention group (solid black line) and the control group (dotted grey line).

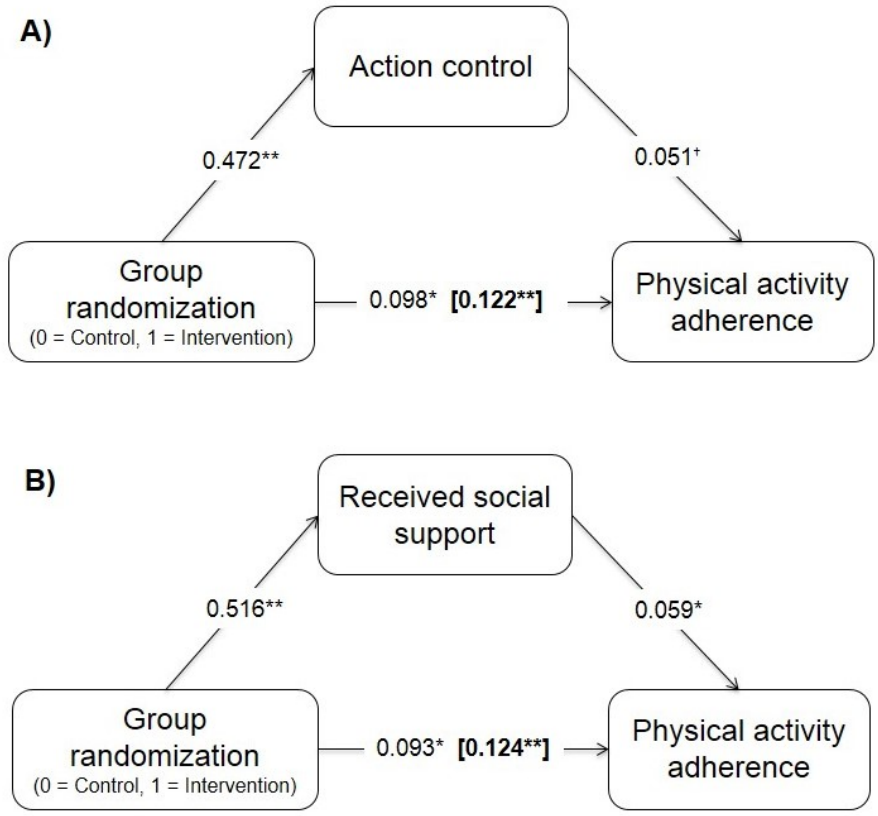

Figure 3 Mediation models summarizing A) action control and B) received social support as separate mediators of physical activity adherence ($N = 119$)

Note. Unstandardized B coefficients are reported. Estimate in brackets refers to the total intervention effect. Analyses were adjusted for gender, device wear-time, and baseline variable of the mediator. † $p < .10$ *$p < .05$, **$p < .01$